

## THE SALT LAKES OF LINGA, VICTORIA

By R. F. CANE, DSC, FRACI

[Communicated by Dr R. R. Garran 13 July 1961]

### Summary

The Salt (Pink) Lakes near Linga in Victoria are described and information is given on the nature and topography of the area. The character of the salt deposits and some features of the annual salt cycle are discussed in detail and an explanation is put forward regarding the occurrence of the 'black mud'.

It is shown that previous data on the nature of the underlying lake structure are in error and it is also demonstrated that there is a regular change in the lakes' composition both temporarily and with varying depth.

The spectacular seasonal pinkness of the lacustrine water is shown to be caused by the presence of enormous quantities of a microscopic halobiontic biflagellate phytozoan containing about 40% of its dry body weight of the red polycene pigment,  $\beta$ -carotene.

### Introduction

The Pink Lakes near Linga in the county of Weeah, NW. Victoria, are an important source of salt for industry and, although salt harvesting by various operators has been carried on for nearly a century, comparatively little is known about the exact conditions of the deposition of salt, the annual changes of brine level, and the nature and composition of the underlying salt formations. With these unknowns in mind, it was decided in 1950 to collect together information of general interest and, at the same time, initiate a programme of experimental work which should, over a period, provide precise information on the character of these interesting deposits.

Other data of a less technical nature may be found in articles by Bain (1947) and by Barrett (1936).

### General Background

The Pink Lakes of the Victorian Mallee lie in the semi-desert region of NW. Victoria, about 260 m. NW. of Melbourne (Fig. 1). The lakes are about 8 m. N. of Linga and Underbool (Fig. 2), which are small towns situated on the railway running W. from Ouyen through Pinaroo to Adelaide. In this area there is a series of small lakes or lagoons running NW. from Underbool. These lakes are described in some detail by Hardy (1914, 1936) although he mentions that they had been on the map for some time under the general name of 'Salt Lakes', salt being produced from them as far back as 1866. Most of the lakes are insignificant, but some are of importance, not owing to size, but because of commercial salt recovery. The main lakes are made up of 3 brine areas called:

- Sailor L. or L. Becking or A lake
- L. Crosby or Gye's L. or B lake .
- Crescent L. or Home L. or C lake.

Other minor lakes have been named, e.g. L. Poulton, a mile or so W. of L. Crosby.

Considerable uncertainty exists regarding the areas of the lakes because the numerous near-flat gravelly beaches and surrounding swamps make impossible any sharp demarcation of shore-line. In addition, because of the flat terrain and shallowness of the lakes, even mild wind causes significant changes in the contour of the water. Perhaps the most reliable data are those of Owen (1943) who gives the areas as:

Sailor L.	.. .. .	168 ac.
L. Crosby	.. .. .	260 ac.
Crescent L.	.. .. .	218 ac.



Fig. 1—Western Victoria showing Mallee region and the position of the salt lakes.

The 3 main lakes are not identical in composition and, as will be demonstrated later, several features of the brine of one lake usually distinguishes it from the others.

### Topography

The position of the lakes is shown in Fig. 2 and 3, and a short description of the area follows. The country is sparsely vegetated and consists of undulating sandhills and patches of loose drift sand. The rainfall varies between  $7\frac{1}{2}$ " and 17" annually with an average of 12", whereas the annual net evaporation is about 40". The average summer maximum temperature is about 90°F, while the average minimum is 60°F. Each lake is surrounded by a ring of gypseous sand dunes covered with open low scrub, the dunes being noticeably higher and more abrupt on the W. margin. The area is barely covered with low scattered vegetation including *Atriplex*,

*Spinifex*, *Melaleuca*, *Callitris*, occasional *Casuarinae* and various mallee eucalypts and acacias. Some of the dominant flora has been attacked in recent years by the parasitic mallee vine. A detailed description of this and the surrounding area has been given by Hardy (1914). It must be remembered, however, that since this description, some important species have been ravaged by parasitic attack; to-day

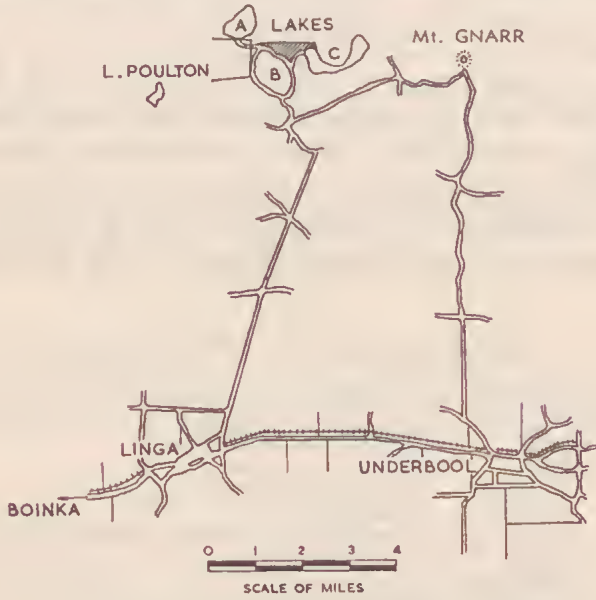


Fig. 2—Salt lakes area, Shire of West Walpeup.



Fig. 3—Salt lakes area showing surface contours—Victorian Railways Datum (after Gloe 1947).

specimens of the *Fusanus* and some acacias are few. The beaded glasswort (*Salicornia*) is found at the lake edges.

Hardy (1914) in his earlier paper states the pink colour of the lakes is caused by chemical impurity in the salt, but later information ascribes the colour to a microscopic pink flagellate. Localized greenish, red and orange patches are of vegetative origin and consist mainly of colonial algae (Hardy 1936).

The area is within the Tertiary Murray Artesian Basin and is just outside the area of useful artesian water as defined by Gloe (1947). There are many brackish bores in the area, the static head of which corresponds nearly exactly to ground level; some of these bores are highly saliferous, but there seems no connection between the artesian and the lakes' waters. Ground water in the sand cover is also appreciably saline.

Underlying the lakes is approximately 200 ft of sand followed by a further 200 ft of clay and limestone. A representative bore log is shown in Table 1 which has been assembled from various sources (Chapman 1916, Gloe 1947, etc.).

TABLE 1  
*Bore Log of Mallee Bore (W. Walpeup)*

Depth (ft)	Record
4-14	Reddish sand and loam
14-21	Fine grained sand
21-56	Fine yellow sand
56-80	Quartz grit
80-114	Sand, quartz, granitic and dune sands
114-120	Clay with shells
120-154	Coarse sand
154-161	Sand with shells
161-245	Sand
245-320	Blue clay and shells (Kalimnan clays)
320-430	Bryozoan limestone
430-468	Blue clay
468-520	Limestone
600+	Brown black lignitic clays
900+	Bed rock of black flint

### Description of the Lakes

The 3 main lakes which make up the Pink Lakes have been well described by Owen (1942) and the following general description has been taken mainly verbatim from his report:

#### SAILOR LAKE

'The lake is roughly pear-shaped in plan tapering to the north. The eastern shore is gently sloping and carries Mallee and Casuarinas. The western shore is flanked by sandhills and steep banks vegetated with Mallee and Spinifex.

There are narrow sandy beaches around most of the perimeter of the lake, but on part of the western and southern margins the shore is formed of ropy masses and nodules of granular gypsum associated with thick deposits of black slimy mud. The masses are soft and spongy to the touch and apparently have been formed by the deposition of gypsum and subsequent bacterial decomposition.'

This mud is discussed later in this report. On the W. dry bank are embedded many crystals of selenite.



Under the influence of prevailing southerly and westerly winds the brine in the lake is driven towards the N. end and consequently a thicker crust of annual salt results near the N. and NE. banks

#### CROSBY LAKE

'This lake is rather similar in shape to Sailor Lake and lies about half a mile south-east from it.

There are gently sloping banks on the northern and eastern sides, and steep banks and small cliffs on the other sides. The western banks consist of sharp sandhills containing gypsum which outcrops about eight or ten feet above the lake level.'

The W. edge of the lake is covered with slimy black mud throughout the year; this mud is up to 2 ft thick. During early spring, the mud gradually extends from this area until it covers the whole lake. Obvious water seepage is also from this general direction.

In other respects, L. Crosby appears to be very similar to Sailor L.

#### CRESCENT LAKE

'This lake has a total area of about 240 acres and consists of two limbs a mile apart and connected at their southern extremities by a relatively narrow neck. Each limb has an area of about 140 acres and the whole lake presents in plan the form of a wide letter U open to the north. The western portion of the lake is rather inaccessible on the northern, eastern and southern sides.'

#### ORIGIN OF THE LAKES

The occurrence of lakes in the NW. Mallee is thought to be associated with shallow depressions caused by the 'solution of underlying beds of limestone and gypsum' (Gloe 1947), but the exact reason is by no means certain. Whether the depressions have been formed by sagging or folding is unknown, and only bores in the lake areas could provide evidence on this point. Whatever the origin, there seems little doubt that once the initial water area has been formed, vegetation around the lake would bind the sand and build up the crater-like formations.

It is suggested that these lakes have a structure similar to many lakes in Australia, i.e. shallow depressions covered by a lenticular semi-pervious gypseous mud pan which acts as a supporting table for local rainfall. Whether the mud pan extends over a large area or there is a series of mud lenses is unknown, but calculation shows that a comparatively small catchment would account for the water intake. E.g. between 15 March and 26 June 1952, the brine in B lake increased in depth by  $4\frac{1}{8}$  in., the rainfall at Ouyen was 2.4" in May and 1.3" in June. Taking the daily rainfall and allowing a 10% loss (this is considered adequate by the State Rivers and Water Commission) it can be shown that a catchment area of approximately  $2\frac{1}{2}$  sq. m. would be sufficient for the increment in level; 60% of such area being provided by the lakes themselves. An examination of Fig. 3 shows that the lakes are in a shallow hollow extending over an area of 28 sq. m. below a reduced level of 175 ft and a much larger area below 250 ft R.L., so that even in periods of high evaporation, sufficient drainage should occur to maintain a supply of brine to the lakes.

The lakes have no visible source of supply of water and no inlet or outlets; water entry is by general seepage from the higher surrounding country. Owen (1942) in his report states—

'The levels of the lake beds approximate closely to the wet season ground water table, with the result that rains of an exceptionally wet winter, such as that just experienced (1942),

do not cause any appreciable rise of the water level in the lakes above that of normal seasons, as it would do if they had impervious bottoms.'

It is shown here that the lakes' level does change with rainfall and moves in sympathy with it (Fig. 5) and it would appear that observers have not given sufficient weight to the effect of wind which will, over such a large flat area, create very great differences in apparent level depending from what direction it blows; the variation of level may amount to several inches within a short period. Although discounted by some, there is little doubt that rainfall is the source of the water and during wet periods small seepages may be seen on the W. banks. Although later information in this paper will show that the water level rises and falls with rainfall, there seems to be a definite time lag between rain and alteration in level. The bands of coarse sand and gravel which are to be found some feet below the banks on the W. and SW sides of the lakes probably act as important aquifers.

The salinity of ground water in this area shows 10-90 gm/litre of chloride and the reason for the salinity has been the subject of several postulates. The retreating Murray Gulf at the end of the Pliocene could have contributed salt which has been brought to the surface by capillary action, but it seems more likely that, at least as far as make-up salt is concerned, the chief source is cyclic, i.e. wind-borne from the sea. (This cyclic salt is always found in semi-desert areas with high evaporation and gentle rainfall so that there is no appreciable run-off and halite plus gypsum remains as a residue from the deposition of sea salt.) In addition, there must be a nice seasonal balance which, with the lowering of the water table in early summer, drains away the bittern containing the magnesium, some sulphate and other more soluble constituents in such a manner that nearly pure sodium chloride is deposited on the surface of the main mass of halite which underlies the brine for a depth of about 4 ft.

This so-called 'annual' salt is deposited on top of the 'permanent' salt, the surface of which corresponds to the level of the summer water-table.

#### NATURE OF THE SALT

Although the salt horizons have been divided into 'annual' and 'permanent', these terms are rather confusing as some of the upper layer of the permanent salt is dissolved during the winter. However, there is some distinction to be made between the salt which is deposited in any one year and the previous years' residual material lower down.

Although there is variation from place to place in the nature of the salt layers, the following can be regarded as a generalized description and Fig. 4 gives an idealized diagrammatic structure, which has been sketched about half size. Six strata can be seen in the upper portion, an uppermost layer (A) of occasional flaky white 'drift' salt (flake or float salt) followed by a layer (B) of thin crystals, plus the well-known 'hopper crystal' (hollow truncated tetragonal pyramids) characteristic of surface growth (Mendeleeff 1891). Below this are scattered cubic crystals of truly transparent salt (C) found hanging on the bottom of the upper layer and formed by crystals growing downwards from the bottom of the floating rafts of salt. This composite layer is very loosely connected to the next layer and often separated by isolated salt crystals bridging the void. This upper composite layer (ABC) is undoubtedly formed by surface evaporation and commences as an aggregate of floating hopper crystals which forms into a larger raft by surface and sub-surface growth. These salt rafts can be seen floating on the brine during periods of high

evaporation and can reach several square feet in size. After a while, wind or other agency causes the raft to sink, whereupon it 'sits' on the subsurface growth of annual salt.

The next lower layer is a fairly compact mass of metamorphosed cubic halite crystals (D) and, as a rule, varying in size from small at the top to large at the bottom. Below this 'annual' salt is usually a thin seam of brown mud and sand which may contain algae (E); the mud is followed by black semi-fluid mud or slime (F) which varies in thickness from nil to 4 inches.

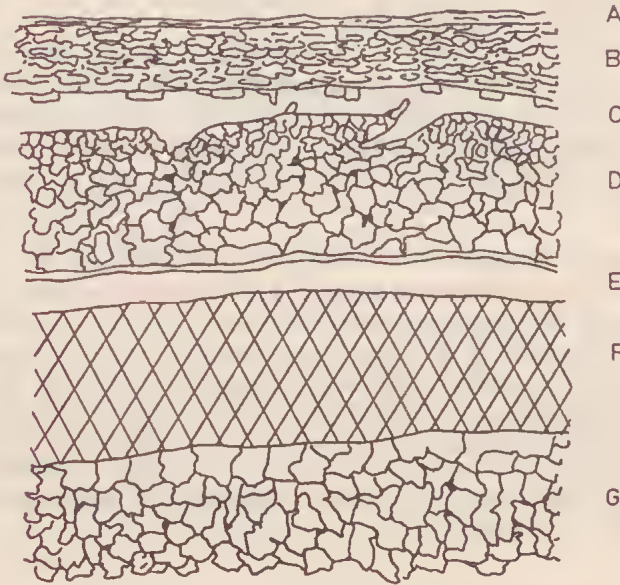


Fig. 4—Section of top layers of salt (diagrammatic).

In some areas of the lakes the black mud extends to the surface and is more or less permanent, especially to the W. from where the brine tends to be diluted; on some W. margins of B lake the mud extends to a depth of 18 in. or more and dead cattle have been observed more or less embedded in it.

Below the black mud is the flat surface of the 'permanent' salt (G), the structure of which is discussed below. The pink salt occurs within band (D), or in (B) when there is an early summer.

By and large, the sequence of events are as follows: The bottom-most mud/salt interface represents the sheared surface from a previous year's salt harvesting and shows appreciable solubility effects during the winter. At the end of the winter, a major area of the lake consists of the permanent salt with a supernatant clear brine solution. At the beginning of the warm period, surface evaporation is not sufficiently rapid to form surface solids but salt begins to form very slowly in the body of the liquid by saturation effects. As the temperature increases, some surface crystals are formed, but the majority are formed still in the bulk of liquid, but at a greater rate, consequently their crystal size is smaller. As small crystals begin to appear at a greater rate, surface evaporation has increased until solid salt in the 'hopper' form appears on the surface; the 'hopper' crystals coalesce forming the



characteristic rafts. The whole process gives rise to the sectional structure described above.

The permanent salt consists of alternating bands of massive clear salt crystals and of dark layers continuing to the bed of the lake about 4 ft deep over a large area. The crystal form and the absence of the 'hopper' variety shows that the 'permanent' salt originated by concentration effects and at no time has there been any major disturbance in its structure. There is no doubt that some of the permanent salt is dissolved during the winter dilution of the lakes, but the main mass of the salt is unaffected as incoming seepage near the top of the salt level tends to stay on the surface because of gravity effects.

The bed of the lake is composed of heavy bluish gypsum clay which provides a semi-pervious claypan for the temporary retention of water. Previous reports state that 'the material down to 4 feet consists of glass-clear recrystallized salt' and there are contradictory statements about its physical structure. Owen (1942) states 'there is much free space probably amounting to 25% of the total volume', while Hall (1943) states that the salt mass is of 'high density and low void percentage'. In actual fact, the porosity of the halite mass depends very much on the season of observation. In order to obtain some unequivocal evidence of the overall nature of the permanent salt, a hole was constructed in B lake approximately 300 yds from the shore. The hole was made by special explosives and a clean section obtained and observed before the brine had a chance of flowing into the hole and disturbing its structure. When a vertical section of the salt was made with a spade, alternate layers of salt and darkish thin seams were seen extending nearly to the bottom of the lake, the dark seams were about  $\frac{1}{2}$  in. thick, while the salt strata varied in thickness from  $\frac{1}{2}$  in. to 3 in., occasional seams of chocolate coloured mud were also observed. The clay bottom of the lake and the surface mud showed the analyses given in Table 2.

TABLE 2  
*Analysis of clay and mud (% w/w)*

	Black mud	Heavy blue clay
H <sub>2</sub> O .. .. .	33.5	10.4
NaCl .. .. .	21.8	14.5
CaO .. .. .	2.6	1.4
MgO .. .. .	1.2	0.2
SO <sub>3</sub> .. .. .	1.6	1.1
Organic insols. .. .. .	12.2	4.9
Inorganic insols. .. .. .	27.5	67.5
	5.6	39.5
{ SiO <sub>2</sub>	20.8	11.0
{ R <sub>2</sub> O <sub>3</sub>	1.1	17.0
{ Rem.		

Salt at different depths is given in Table 3.

An inspection of Table 3 shows a regular trend in composition through the depth of the lake, the reason for which will be discussed later.

Although, as mentioned earlier, much of the brine addition is along the surface of the lake, some flows laterally along the salt strata lower down and causes dissolution of the permanent salt at crystal faces and along edges; these solids are



TABLE 3  
*Analysis of salt from different depths (% w/w—dry basis)*

	Drift Salt	Surface Salt	Band 15 in. from bottom		
			Upper	Lower	Bottom
NaCl .. .. .	99.3	98.0	88.0	74.9	66.3
SO <sub>4</sub> .. .. .	0.4	0.8	6.0	9.4	12.0
CaO .. .. .	0.1	0.2	1.3	1.8	3.9
MgO .. .. .	0.1	0.4	0.1	0.1	0.6
Insolubles .. ..	—	9.0	4.6	13.6	18.9

replaced by recrystallization during summer. During the winter period of high voidage, any accumulation of calcium sulphate in the salt tends to settle towards the bottom of the lake. The reason for the stratified light/dark seams in the permanent salt is not at all clear; perhaps there are bands of denser salt which hinder the settling of darker insolubles.

#### THE OCCURRENCE OF THE BLACK MUD (SLIME)

Black slimy mud is universally found associated with salt in salt lakes, in salt beds and in solar crystallizers. Most rock salt deposits are interstratified with bituminous black sapropelic sediments similar to that of the Linga Lakes.

Black muddy deposits are formed in lakes where water circulation is low and there is a lack of free oxygen in solution. Under such conditions, organic matter is not destroyed but accumulates together with suspended calcium sulphate, iron salts and humic acids. Sulphate-reducing bacteria then attack the gypsum and the resulting calcium sulphide is hydrolysed to the hydroxide with liberation of hydrogen sulphide which precipitates the iron, as well as producing the foul odour associated with these muds.

The black mud is an intimate mixture of decaying organic matter, iron sulphide, humic acid derivatives, calcium sulphate and other inorganic salts characteristic of such matter. In the summer when the brine is saturated, sulphate reducing bacteria can be active no longer and clean salt is deposited.

The quantity and distribution of the mud is very variable and, in some years, its formation is very meagre. In general, the mud is more abundant towards the W. shores of the lakes—the side from which dilution occurs. Some spots within the mud areas yield superb crystals of selenite.

#### Annual Cycle of Brine

Since the initial publication of data on these lakes nearly a half century ago, there has been considerable difference of opinion regarding the rise and fall of the brine level, alteration of salt level and changes in composition of the brine. In order to provide some reliable answers to these unknown, a series of observations have been made over the last 10 years which will answer some of the above queries.

#### CHANGES IN THE BRINE LEVEL

Early in 1952, a set of calibrated stakes (150 ft apart) was driven into the salt in a N.-S. direction radially out from an experimental salt plot, 1000 ft from the shore on B lake. The positions of the stakes were fixed and regularly checked by an accurate shore sight. Readings were taken during periods free from wind and

the brine levels recorded at the experimental plot (corrected, if necessary, for any differential between the outer stakes).

Brine and salt levels over a 2-year period are shown in Fig. 5 as well as the monthly rainfall for Underbool, the nearest official weather station. The brine data have been shown as a smooth curve as it is obviously impossible for any sharp discontinuities to occur. The graphs show that:

1. There are regular changes in the brine level.
2. There are similar, although not so pronounced, changes in salt level.
3. The changes are, in a general way, in sympathy with the rainfall although they tend to lag somewhat in time. (\*Each month's rainfall has been shown in Fig. 5 at the end of the month, to minimize the apparent time lapse.)

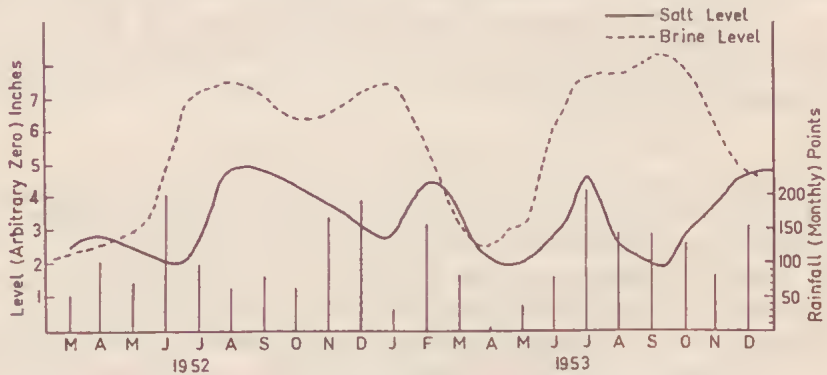


Fig. 5—Changes of level and rainfall with respect to time.

This suggests that subsurface drainage takes a time to reach the lakes proper and that a new influx of salt in solution takes some time to crystallize out. The gradual subsidence in salt level in the late winter seems to be caused by solution of some of the 'permanent' salt as the surface of the salt seemed not very distorted by solubility effects. A sequence of events is visualized as follows:

Rain in May 1952\* caused a slow increase in the brine level over May/July, and a corresponding build up of salt over June/August. Little rain between July and September caused a gradual decline in the lake level by surface evaporation, and at the same time, a certain amount of salt was carried away by drainage. More rain in October/November\* was shown in the rise in the lake's level, and further dissolution of salt. With an increase in temperature in January, there was a sharp drop in the lake's level, and although the January rainfall was relatively high, it was not shown up in the water level because of high evaporation, but there was a sudden increase in salt level. During March, the level of the brine was below the salt level and harvesting took place. With a decrease in surface temperature and increasing rain in April/May, a certain amount of dissolution and decrease in salt level occurred. However, in June\*, with good rainfall, further salt was introduced into the lake with build up in both brine and salt level until July. In the period July/September, moderate rainfall was about equivalent to evaporation, but the surface brine again became unsaturated, with a drop in the salt level caused by dissolution. It seems probable that in a general manner, this cycle is repeated on an annual basis.

## THE CHARACTERISTICS OF THE BRINE

Samples of brine from the Linga Lakes were collected during the period 1952/1954 and again in 1960/1961, the writer being absent from Victoria during the hiatus. In most cases 2 samples were taken on each occasion, one at the surface of the brine and another approximately 2 ft down.

With regard to difference in composition between lakes, it would be prolix to give the many hundreds of analytical figures which are available. It may be stated, however, that without any significant exception, the following rules apply:—At any given time, the brine of the 3 lakes shows—

1. a decreasing NaCl concentration in the order—lake A, lake B, lake C;
2. an increasing sulphate concentration in the order—A, B, C—A being about two-thirds of B, and C being about twice A;
3. an increasing brine density in the order of A, B, C, there being little difference between B and C;
4. magnesium increases in the order A, B, C—lake C has considerably more magnesium than either A or B;
5. calcium decreases in the order A, B and C, although there are a few irregularities.

In order to illustrate the generality of 1, 2 and 3 above, it is pointed out that, of 106 analyses done in 1952, only 4 were contrary to the above, and all deviations except one were less than the estimated experimental error.

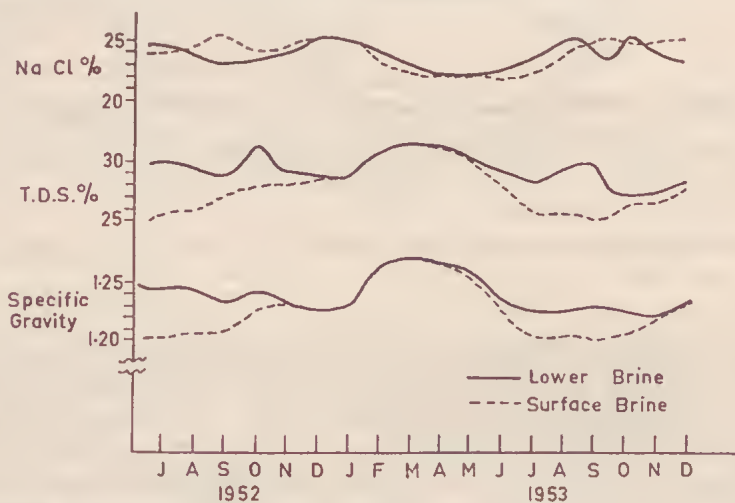


Fig. 6—Graphical representation of monthly changes in certain physical properties of the brine.

Fig. 6 shows the changes in specific gravity and chloride with time; included in the graph is a curve showing 'Total Dissolved Solids' (T.D.S.) determined by evaporation. The specific gravities have been corrected to 20°C using data from the International Critical Tables. The chloride was determined by the standard Volhard analysis and expressed as NaCl. Samples were taken from A lake and B lake, but only B is shown because, with the provisos mentioned above, there is little significant difference between the two. The curves in Fig. 6 cover a period of 1½ years in 1952/53 and although similar data were obtained for the periods

June/December 1958 and for some of 1959/1960, they are not reproduced here as the overall picture is the same and it would be difficult to show the broken shorter periods.

Although the changes in specific gravity and T.D.S. are as might be expected, i.e. show a rise in concentration in the summer and a decrease in winter, the reverse takes place in common salt concentration, the shape of the NaCl % curve being approximately the inverse of the two lower pairs of curves. Furthermore, the brine at the surface of the lake is often greater in NaCl concentration than that lower down. The reason for the apparent abnormality is illustrated in Fig. 7 which shows magnesium and sulphate analyses.

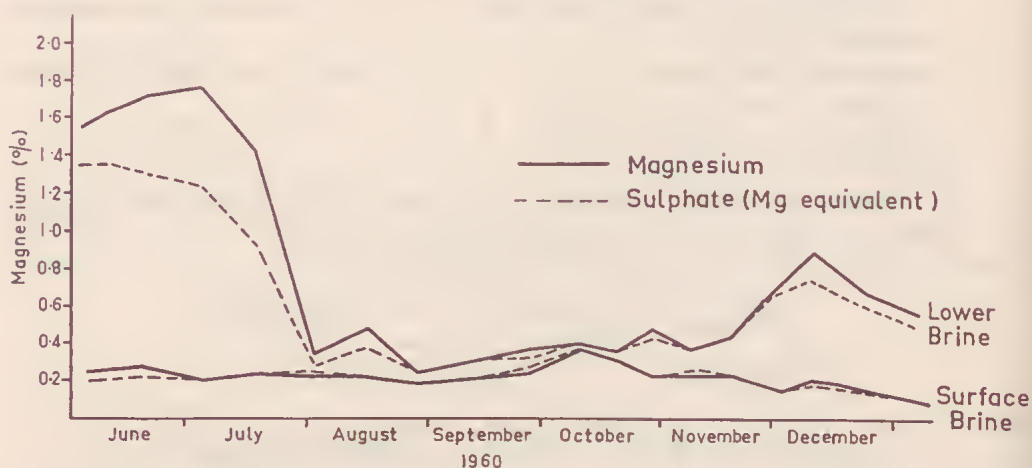


Fig. 7—Changes in magnesium in the brine related to sulphate content.

From the similarity of the graphs, it may be accepted that sulphate ion is introduced to the lakes as  $MgSO_4$ . The analysis of the system  $NaCl/MgCl_2-MgSO_4/Na_2SO_4$  is complicated by the metathesis  $2NaCl + MgSO_4 \rightleftharpoons MgCl_2 + Na_2SO_4$  and by the lack of equilibrium data in the temperature range  $10-20^\circ C$  for the concentrations under consideration. Information from this survey reveals nevertheless that NaCl is not the only compound playing an important role in the brine system of the lakes (in March 1952,  $MgSO_4$  reached 6.7%), that the chemistry of the surface waters differs from that at depth and that a lowering of NaCl concentration does not necessarily mean a more dilute salt solution.

Although all samples were analysed for calcium, the maximum amount present was only 0.06% and the curves followed the T.D.S. curves. It is felt that the calcium salts do not play an important role in the halurgy of the lakes and, for these reasons, it is not proposed to deal specifically with the chemical aspects of calcium.

It would be misleading as regards composition to cite a typical salt analysis as it depends so much on where sampled, at what depth, season, etc. By taking



small samples over a large area and bulking them, an 'average' wet sample showed the following analysis calculated on a dry basis—

NaCl	.. .. .	91.43
MgCl <sub>2</sub>	.. .. .	1.97
MgSO <sub>4</sub>	.. .. .	4.30
CaSO <sub>4</sub>	.. .. .	0.73
KCl	.. .. .	0.04 ?
Inorganic insols.	.. .. .	0.59
Organic insols	.. .. .	0.02
n.d.	.. .. .	0.82

### The Red Colouring Matter

The occurrence of living colouring matter in salt lakes, saline ponds and puddles is well known to workers in this field, but is little known outside it. The colour of the Linga Lakes has been variously attributed to mineral matter (manganese and iron), algae, bacteria and optical effects. It has now been proved that the pink colour is caused by a large seasonal population of the biflagellate halophilic phytozoan, *Dunaliella salina* Dun. (Teodoresco 1904), a most interesting alga which is fairly common in similar environments throughout the world.

*D. salina* was first described by Hamburger (1905) and later in detail by Lerche (1937). Although somewhat curious in that it lives in strong brine, perhaps the most extraordinary feature of the metabolism of *Dunaliella* is that it secretes either chlorophyll or carotene depending on the salt concentration of its environment. Fox and Sargent (1938) state—

'Synthetic brines containing 15% NaCl plus traces of nutrient salts, inoculated with the halophyte, produce flourishing cultures of brilliant green colour, whilst in similar cultures containing 25% NaCl, an actively multiplying population of the same species is of a brick red colour. Intermediate concentrations of NaCl give rise to intermediate variations in colour.'

The red colour of *Dunaliella* is caused by large amounts of  $\beta$ -carotene which is easily extracted from the organism en masse by shaking the red coloured brine with ether from which the polyene crystallizes in superb ruby-coloured glistening platelets. The organism has a specific gravity less than that of the brine and, as it shows positive photo-taxis (Blum 1933), tends to accumulate on the surface and in quiescent pools may congregate until the brine has the consistency and colour of tomato soup. During October 1960, the lakes showed a high pinkness and several gallons of the supernatant red scum were brought to Melbourne for examination. Microscopic examination showed beyond doubt that the colour of the 'Pink Lakes' is caused by *Dunaliella salina* and that, in the material examined,  $\beta$ -carotene occurred to the extent of about 40% of the body weight of the organism.

What local circumstances are responsible for the occurrence of what must amount to tons of the alga in one year and its absence in another is unknown. Its growth, however, is fairly ephemeral, as 2 weeks after the above samples were collected, the lakes had lost their colour and no local concentrations of the halophyte could be seen.

An interesting side-light to this work was the occurrence of a persistent sweet violet-like odour in the salt heaps, caused by the presence of  $\beta$ -ionone from the decomposition of the algal carotene.

## Acknowledgements

The writer would like to acknowledge the field work of Mr J. Calland of Ouyen without whose assistance this work would not have been possible. He would also like to express his gratitude to Imperial Chemical Industries of Australia & New Zealand Limited for permission to publish this work.

## References

- BAIN, A. D., 1947. Salt production in Victoria. *Min. & Geol. Jour. Vict.* 3: 4.
- BARRETT, C., 1936. Victoria's Pink Lakes. *Aust. Mus. Mag.* 6: 91.
- BLUM, H. F., and FOX, D. L., 1933. Light responses in the brine flagellate *Dunaliella salina*. *Univ. of Calif. Publ. Physiology* 8 (3): 21.
- CHAPMAN, F., 1916. Cainozoic geology of the mallee and other Victorian bores. *Geol. Surv. Vict. Records* 3 (4): 325.
- FOX, D. L., and SARGENT, M. C., 1938. Variations in chlorophyll and carotenoid pigments of the brine flagellate *Dunaliella salina* induced by environmental concentrations of sodium chloride. *Chemistry & Industry* 57: 1111.
- GLOE, C. S., 1947. *The Underground Water Resources of Victoria*. Vol. I. State Rivers and Water Supply Commission. Government Printer, Melbourne.
- HALL, A. M., 1943. Private report on the salt lakes—Melbourne.
- HAMBURGER, C., 1905. Zur Kenntnis der *Dunaliella salina* und einer Amöbe aus Salinenwasser von Cagliari. *Archiv für Protistenkunde* 6: 111.
- HARDY, A. D., 1914. The Mallee: Ouyen to Pinaroo. *Vict. Nat.* 30: 148.
- , 1936. The Pink Salt Lakes and their Algae. *Vict. Nat.* 52: 199.
- HILLS, E. S., 1939. The physiography of North-West Victoria. *Proc. Roy. Soc. Vict.* 51: 297.
- LERCHE, W., 1937. Untersuchungen über Entwicklung und Fortpflanzung in der Gattung *Dunaliella*. *Archiv für Protistenkunde* 88: 236.
- MENDELEEF, D. I., 1891. *The Principles of Chemistry*. Longmans, London, I: 416.
- OWEN, H. B., 1942. *Preliminary Report on the Salt Resources of the Pink Lakes in the County of Weeah, Victoria*. Mineral Resources Survey, Department of Supply & Shipping, Canberra. 15 Sept. 1942.
- , 1943. *Salt Resources of the Pink Lakes in the County of Weeah, Victoria*. Mineral Resources Survey Report No. 1943/12. Plan 824. Department of Supply & Shipping, Australia. 25 Feb. 1943.
- TEODORESCO, E. C., 1904. Organisation et développement du *Dunaliella*, nouveau genre de Volvocacee-Polyblepharidee. *Beihfte Bot. Centralblatt* 18: 215.